STUDIES IN DISPLAY SYMBOL LEGIBILITY

Part XII. The Legibility of Alphanumeric Symbols for Digitalized Television

NOVEMBER 1966

G. C. Kinney
M. Marsetta
D. J. Showman

Prepared for
DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 7030
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-5165

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FOREWORD

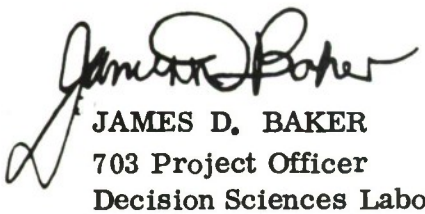
This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966; "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background Relation, and Surround Brightness on the Legibility of Capital Letters," by D. Shurtleff, B. Botha, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966; "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on the Legibility of the Common Five-Letter Words," by G. Kosmider, The MITRE Corp., Bedford, Mass., ESD-TR-65-135, May 1966; "Studies of Display Symbol Legibility, VI: Leroy and Courtney Symbols," by D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-136, May 1966; "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945- and 525-Line Resolutions," by D. Shurtleff and D. Owen, The MITRE Corp., Bedford, Mass., ESD-TR-65-137, May 1966; "Studies of Display Symbol Legibility, VIII: Legibility of Common Five-Letter Words," by G. Kosmider, M. Young, and G. Kinney, The MITRE Corp., Bedford, Mass., ESD-TR-65-385, May 1966; "Studies of Display Symbol Legibility, IX: The Effects of Resolution, Size, and Viewing Angle of Legibility," by D. Shurtleff, M. Marsetta and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-65-411, May 1966; "Studies in Display Symbol Legibility, X: The Relative Legibility of Leroy and Lincoln/MITRE Alphanumeric Symbols," by D. J. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-115, August 1966; and "Studies in Display Symbol Legibility, XI: The Relative Legibility of Selected Alphanumerics in Two Fonts," by G. Kinney and D. Showman, The MITRE Corp., Bedford, Mass., ESD-TR-66-116, August 1966.

ABSTRACT

The relative legibility of numerals and capital letters in four fonts, standard Leroy, an Idealized Hazeltine, a Simulated Hazeltine and a Modified Idealized Hazeltine, was studied in three experiments using a controlled exposure time, single-symbol, recognition test. The Hazeltine fonts were constructed of TV lines digitally controlled to generate symbols of elements in a five-column by seven-row rectangular matrix. The Hazeltine font was found to be as legible as the Leroy, but losses in legibility were found for photographic simulations of the symbols as they appear on a TV tube. The modified font was found to be superior in legibility, and is recommended for display use. Further study should be done on a TV tube and would best employ other kinds of legibility tests.

REVIEW AND APPROVAL

This Technical report has been reviewed and is approved.



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The cooperation of the Hazeltine Electronics Division of the Hazeltine Corporation, Greenlawn, New York, in providing technical details and photographic reproductions of their alphanumerics is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (CONCL'D)

SECTION I

INTRODUCTION

The legibility of alphanumeric symbols on a television monitor is one of the factors in determining the capacity of TV as a display medium. Symbol legibility, in turn, depends upon many peculiarities of the equipment and its adjustments which affect the symbol's appearance. For example, in closed-circuit TV systems, symbols on the monitor may be generated by a camera aimed at printed materials, or by digital circuitry which generates the symbols by modulating the monitor's scanning beam. Each method has its peculiarities. One of the big differences between them is that the digital method provides a better control of the alignment of the scanning line with the horizontal strokes of the symbols. There are other differences between the two methods which are suspected of influencing legibility, but more is known about the peculiarities of the camera method. The effects of symbol font, symbol resolution, alignment and orientation of scanning line and symbol strokes, and other features of the camera method have been studied, and are fairly well understood (see References 1 to 16). Less is known about the legibility of alphanumerics on digitalized TV. Since the digital method has certain apparent advantages, the legibility of the alphanumerics in one such system was studied, and is reported in this paper.

The system of concern is a version of the Hazeltine Alphanumeric Generator. The symbols in the present case may be described as consisting of small segments of the active line which generate a 5 by 7 rectangular matrix, such as that in Figure 1. As the active line scans a row of elements, it can be turned on and off to draw any one, two, three, or four, or all five of the row elements, the adjacent row elements overlapping slightly. When the beam sweeps the next run, it generates other elements, and the elements

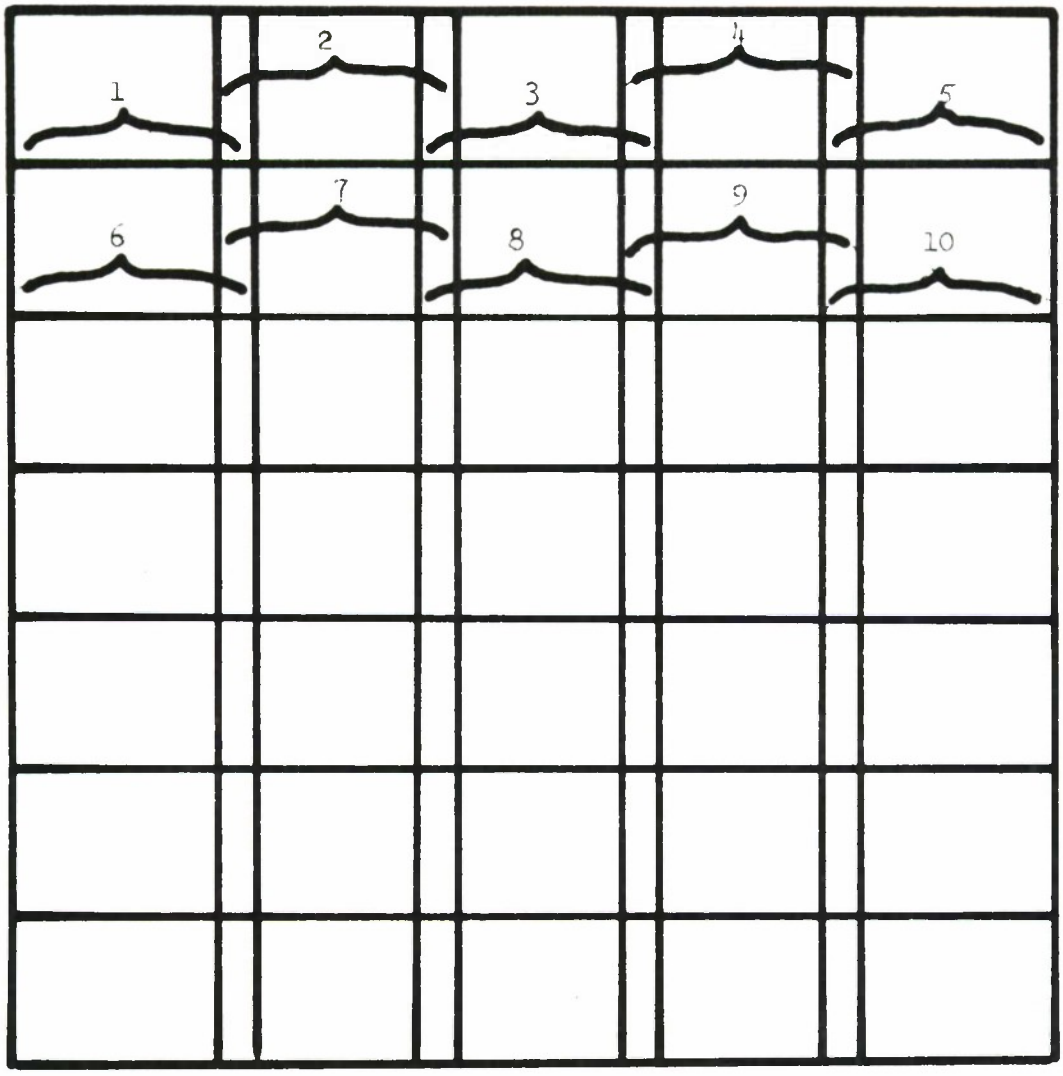


Figure 1. The 5 by 7 Element Matrix From Which the Hazeltine Symbols Were Generated. (The first ten elements are numbered and marked by the inclusion signs.)

of seven rows comprise the symbol. The elements in Figure 2 have been filled in to show how the numeral 2 is generated. A set of ideal alphanumerics is shown in Figure 3; it is called "idealized" because each element is carefully constructed and placed.

Of course, the symbols are not so neat in appearance on the TV monitor. The beam is not so sharply edged and cannot be turned on and off so exactly, and the phosphor is of limited resolution. These factors, and the inevitable compromises of electronic engineering, produce a symbol different from its idealized intent. When the symbols in Figure 3 were programmed and displayed on a TV tube, their appearances were closer to what is shown in the photographic reproduction in Figure 4. The apparent degradation in symbol structure consists mostly of rounding off the corners of the elements. Occasionally there is a slight error in the vertical registration of the beam. The errors in the bottom stroke of the G and in the center of the K can be eliminated by adjustments of the circuitry. The discrepancies between the symbols in Figures 3 and 4 are less apparent on the display because the symbols on the tube are roughly one-half as big concealing the inaccuracies seen in the photograph. The symbols in Figure 4 can be adjusted in size so that they simulate the symbols on the tube fairly well.

The legibility of the H/ANG symbols was studied in three experiments reported in detail later in this report. The first experiment compared the Idealized Hazeltine font in Figure 3 to the standard Leroy font in Figure 5; its purposes were (a) to establish how well the Idealized Hazeltine compared in legibility to a more conventional font of good legibility, and (b) to discover which of the Idealized Hazeltine symbols were most frequently confused with each other as a guide to design changes which would increase the font's legibility.

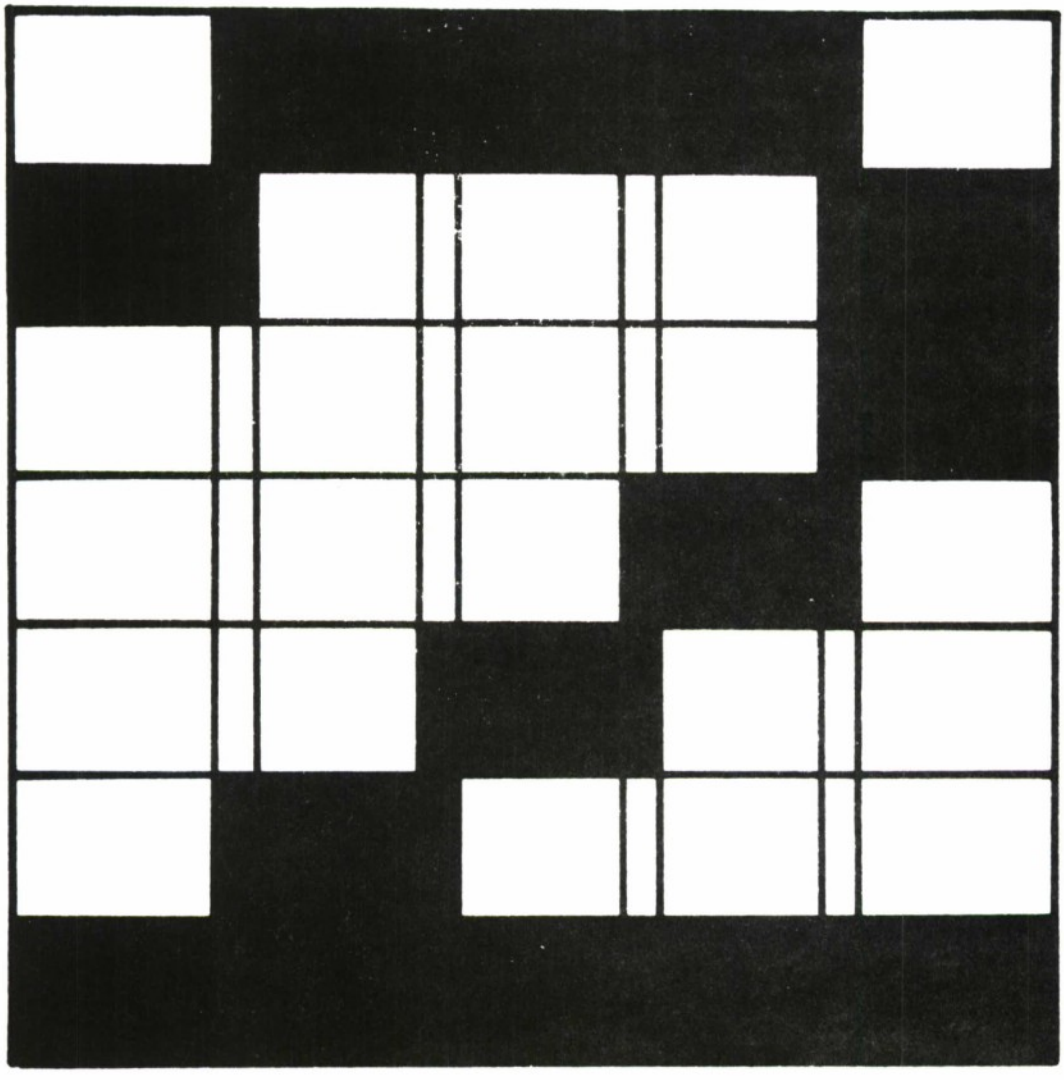


Figure 2. The Elements of the Matrix of Figure 1 Are Filled In To Show How The Numeral 2 Is Generated. The Numeral Is The 2 of The Idealized Hazeltine Font.

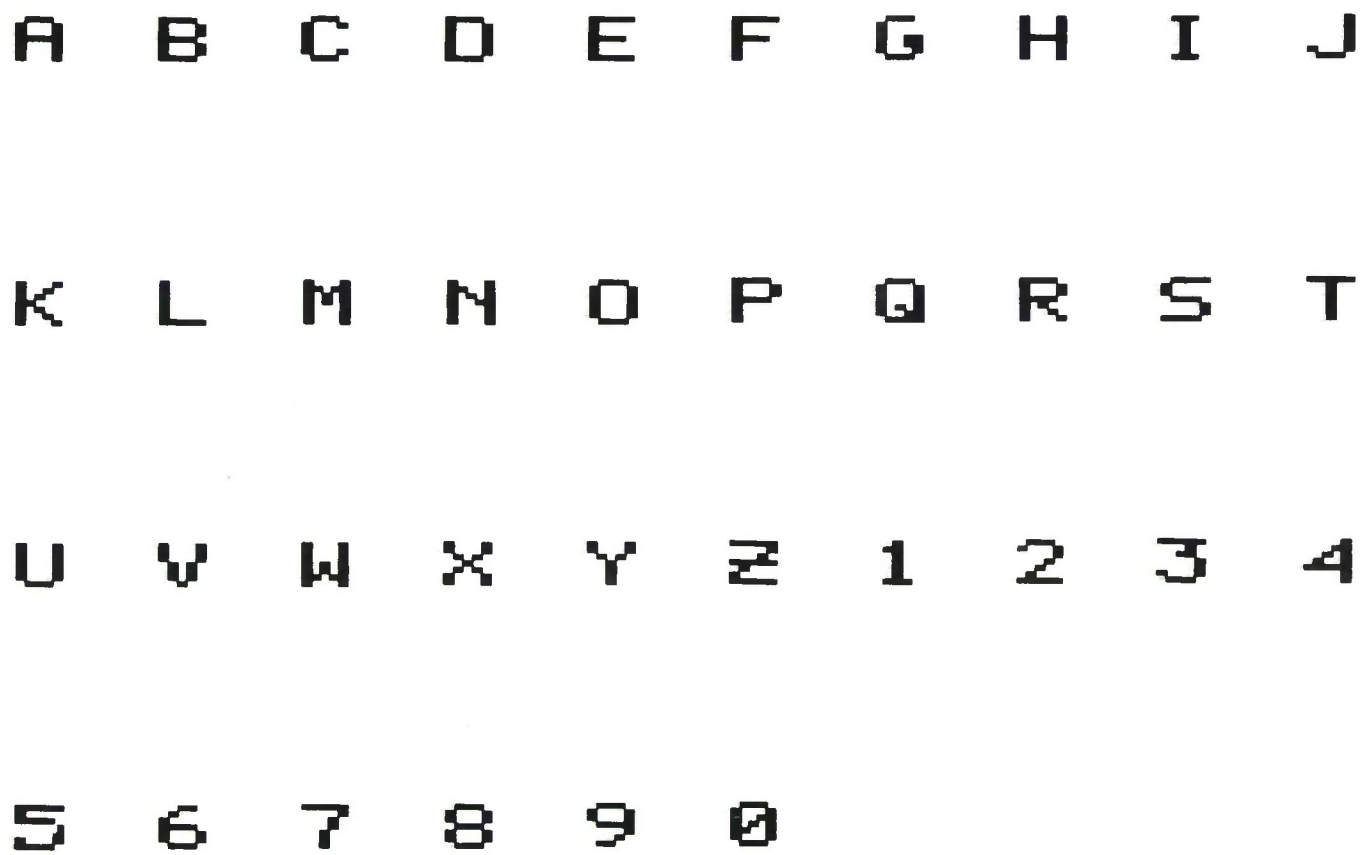


Figure 3. The Idealized Hazeltine Font Used In The Experiment

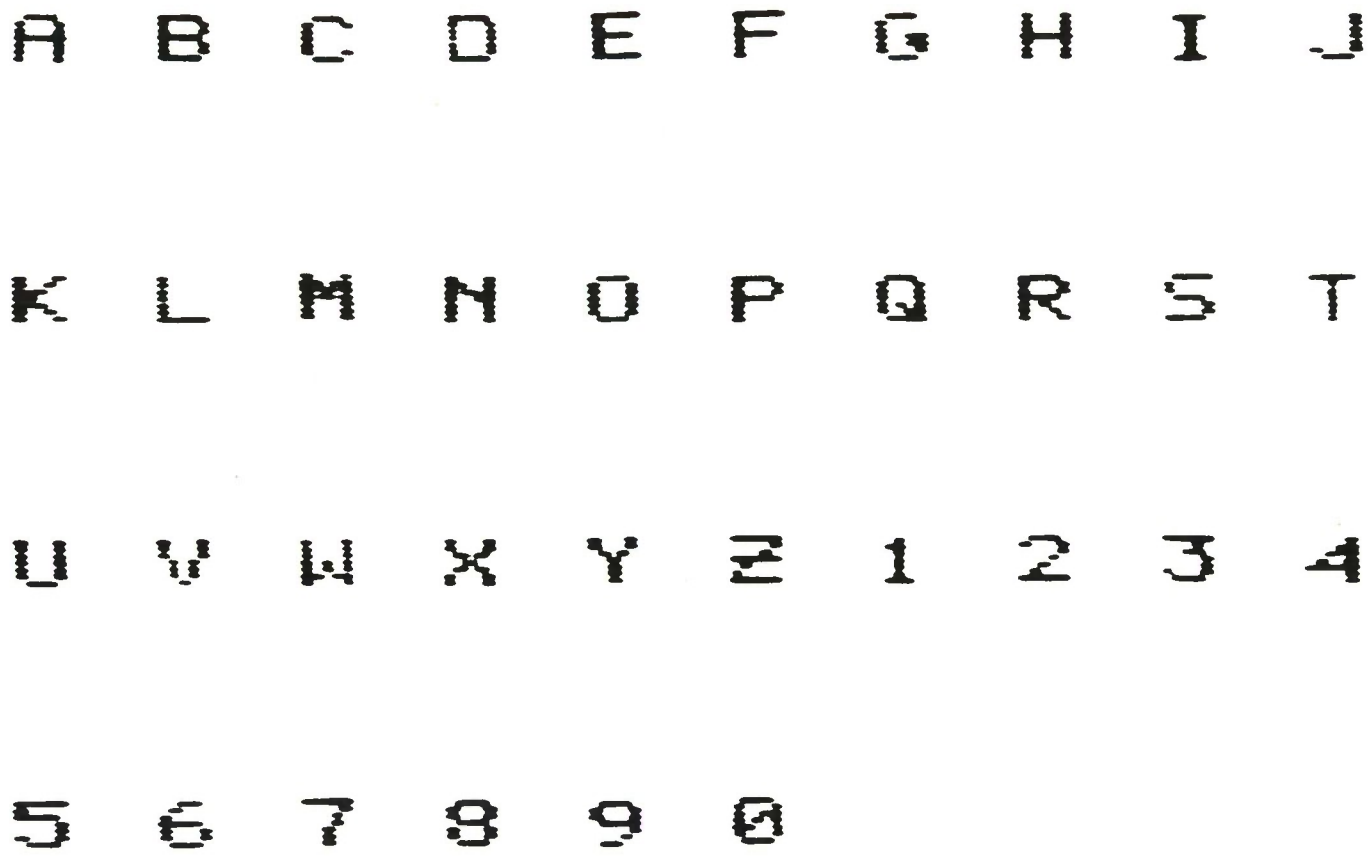


Figure 4. The Simulated Hazeltine Font Used In Experiment 2

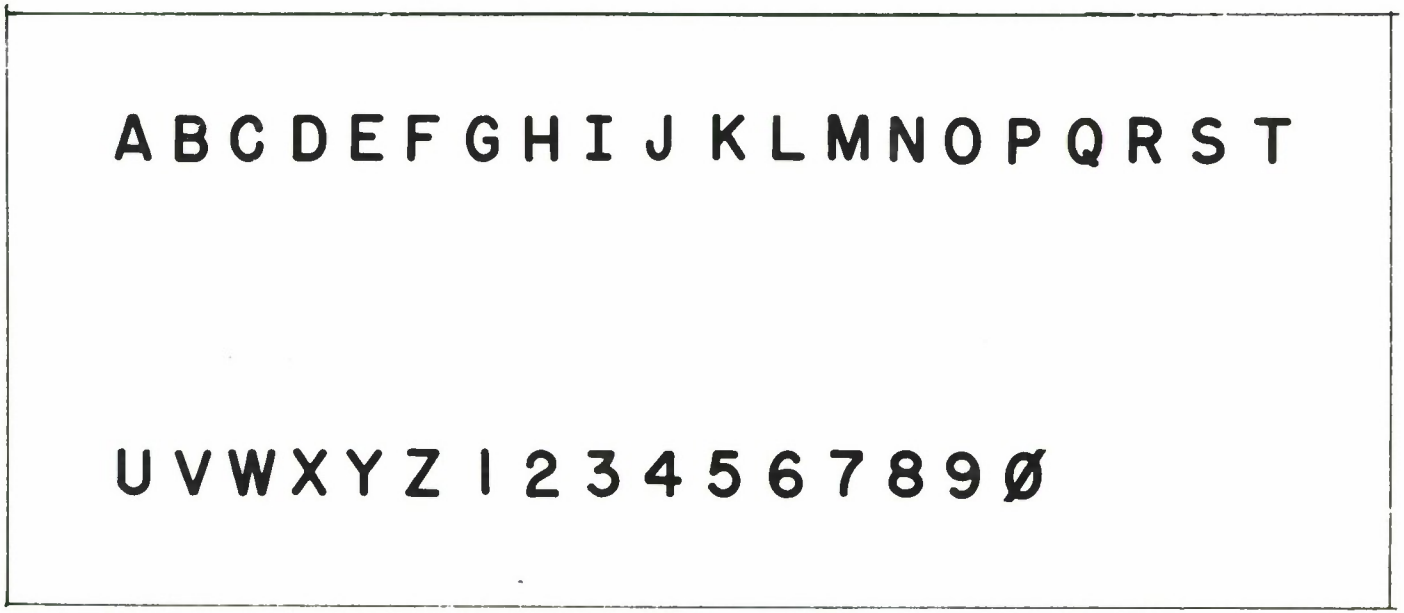


Figure 5. The Leroy Font Used In Experiments 1 and 3

In the second experiment, the Idealized Hazeltine font was compared with the Simulated Hazeltine font in Figure 4; its purposes were (a) to determine what losses in legibility may be expected when the symbols are printed on a cathode ray tube, and (b) to discover similarities and differences among the intersymbol confusions of these two sets of alphanumerics.

The third experiment compared the Idealized Hazeltine font in Figure 3 with the Leroy in Figure 5 and with a Modified Idealized Hazeltine font shown in Figure 6; its purposes were (a) to test the effects upon legibility of certain symbol design changes (the Leroy and Idealized Hazeltine were redone to control for practice effects), and (b) to study intersymbol confusions related to the design changes.

In each experiment the fonts were studied by having human subjects attempt to identify the symbols when they were shown one at a time for a brief period. The same subjects were used in all three experiments, and the equipment and other conditions were held constant throughout the study. The details of the procedure, the results, and the discussions are taken up later, but a summary of the conclusions and recommendations seems appropriate here.

Experiment 1 compared Leroy and Idealized Hazeltine; conclusions were (a) the two fonts are generally equivalent in single-symbol legibility, and (b) the Idealized Hazeltine font showed high error rates for B, C, D, O, Q, S, 5, and 8. Recommendations were to perform the second experiment.

Experiment 2 compared Idealized Hazeltine and Simulated Hazeltine; conclusions were (a) the Simulated Hazeltine symbols are not as legible as the Idealized Hazeltine symbols, (b) the errors made with the Simulated Hazeltine were mostly on B, C, D, G, O, P, S, 5, 8, and Ø (P, F, I and 1 also had a high error rate), and (c) the rank order of symbols from highest

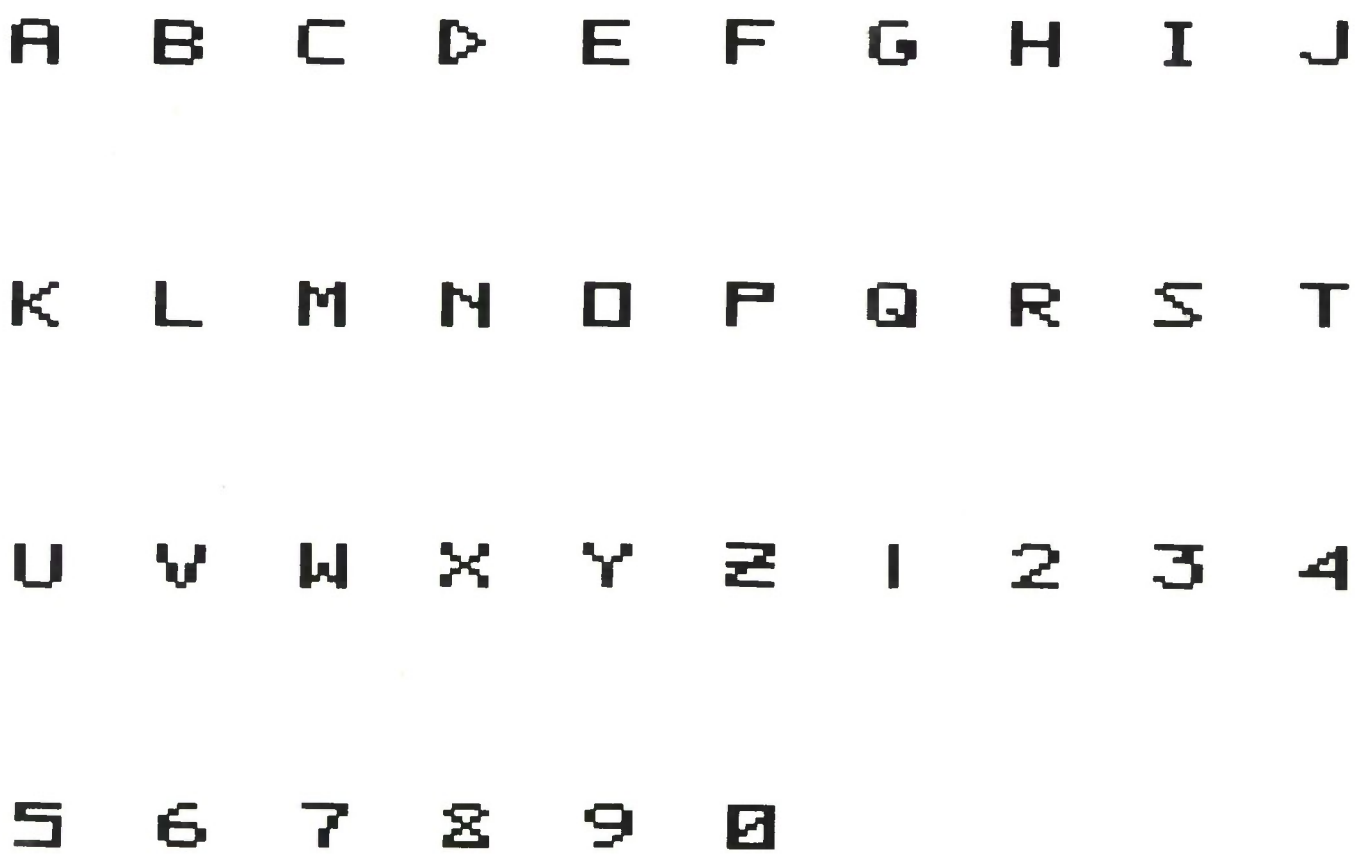


Figure 6. The Modified Idealized Hazeltine Font Used In Experiment 3

to lowest error in the Idealized Hazeltine font was correlated highly with the same rank order of symbols in the Simulated Hazeltine font. Recommendations were (a) the general legibility of the Hazeltine font on the display should not be judged from that of the Idealized Hazeltine font because of the larger error rate for the Simulated font, and (b) because the distribution of errors among the thirty-six symbols was much the same for both fonts, the distribution of errors and the occurrence of intersymbol confusions may be studied with the Modified Idealized font, thus avoiding the need for scope photography and simplifying the process of modifying the symbols by requiring only art work.

Experiment 3 repeated the first experiment for Leroy and Idealized Hazeltine and included the Modified Idealized Hazeltine font in Figure 6; conclusions were (a) the subjects improved their performance with practice, (b) the error rates for Leroy and Idealized Hazeltine were again comparable, and (c) the Modified Idealized Hazeltine was significantly more legible than the original font. Recommendations were (a) the Modified Hazeltine font should replace the original font for use on the display tube, the specific symbol changes being retained as shown, and (b) further study should be made of the Modified Hazeltine font in tests using other reading tasks, such as word recognition.

SECTION II

EXPERIMENT 1

APPARATUS

The subject sat at a table on which was placed a tachistoscope (see Figure 7). This device is a T-shaped tube of rectangular cross-section arranged so that the subject can peer into one end of the cross of the T to see the other end at a distance of 54 inches. A beam splitter is mounted in the tube at the intersection of the cross and stem of the T to reflect the image of the base of the stem and to transmit the image of the opposite end of the cross at the same time. The two end spaces are thus seen visually superimposed and at the same apparent distance from the subject's eyes. At the far end of the cross of the T, a rectangular hole is cut into the center of the end. The film bearing the symbols was passed behind this hole.

The film end of the tube was kept dark, and the end of the stem of the T was covered with a fine-grained, white, styrofoam plastic and lighted continuously by an external incandescent lamp. A set of four black lines was drawn on the white plastic in the form of a large plus sign with its center removed and arranged so that the center of the open space between the lines was visually coincident with the center of the rectangular hole for the film. With this background, the subject could fixate the eyes on the place where the symbol would appear when it was exposed. The symbols were made clear on an opaque, 35 mm strip of DuPont Cronar Ortho A Litho film lighted from behind by a battery-powered incandescent lamp. A mechanical shutter was placed in the light path between the film and the lamp in order to control the duration of symbol exposure. The subject had a switch which operated the

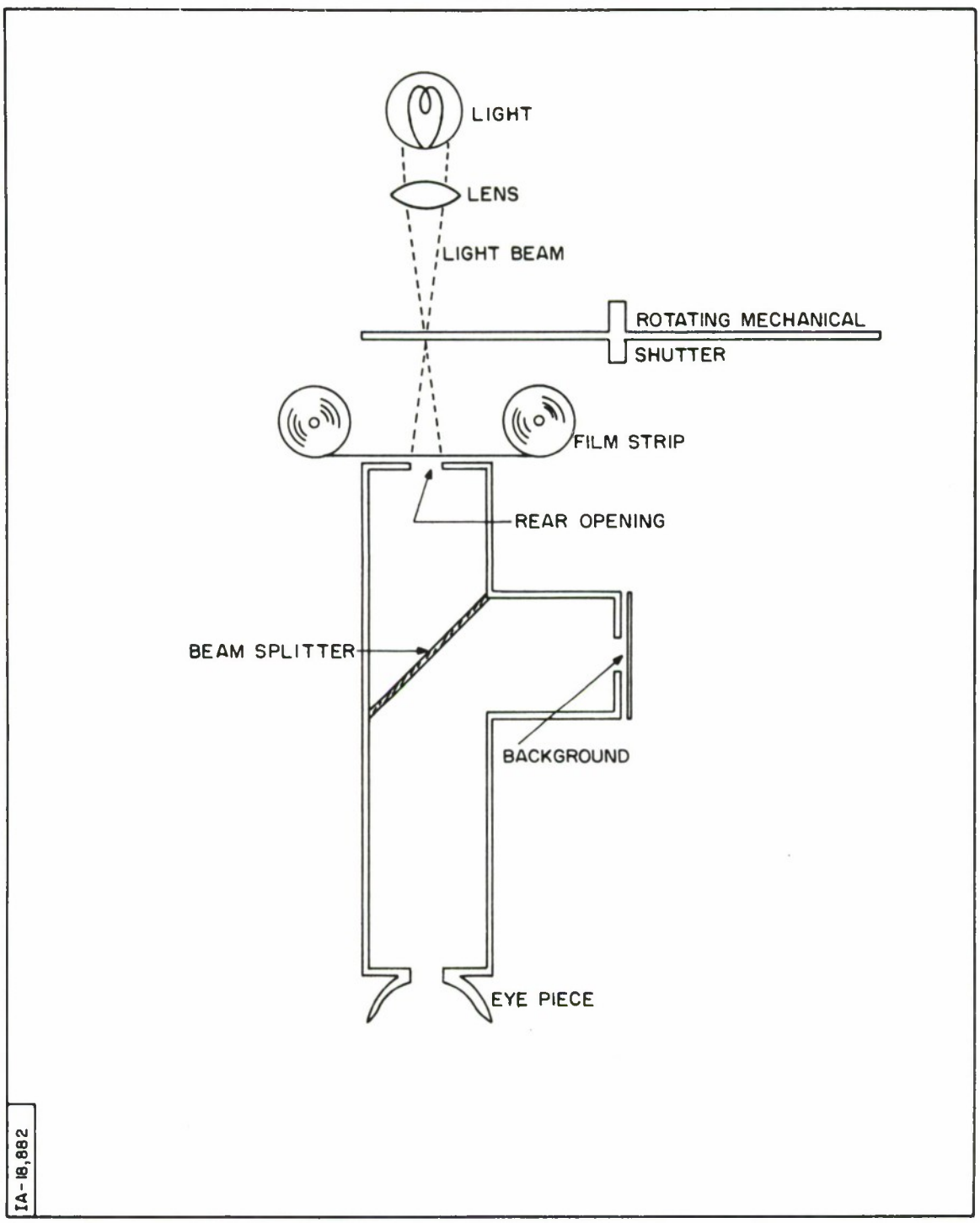


Figure 7. The Tachistoscope Used To Expose the Symbols to the Subjects

shutter. When he focussed on the fixation point and was ready to see the symbol, he pressed the switch to operate the shutter and expose the symbol for 5 milliseconds.

The brightness of the background was measured through the eyepiece with a calibrated Spectra Brightness Spot Meter, and set to 1 foot-lambert. The brightness of the symbol was similarly set to 8 foot-lamberts, with the background lighted, by putting an exposed and developed frame of the film at the film opening. Brightness measurements were made before and after each session (the term "session" is defined under Procedure). Background brightness did not vary by more than ± 0.1 foot-lambert, nor symbol brightness by more than ± 0.4 foot-lambert. Both lamps were white in color.

The symbols were as shown in Figures 3 and 5, which are contact prints of identical film strips. The stroke width of the Leroy set was made equal to the average stroke width of the Idealized Hazeltine. The height of the symbols subtended approximately 16 minutes of arc at the subject's eyes. There were 180 symbols in each font on each film strip. The symbols occurred five times each, and at random with respect to alphabetic and numeric order. By starting from either end of the strip, and by proceeding one or two frames at a time, the experimenter could choose from four different random sequences of symbol occurrence.

The experiments were conducted in a sound-shielded room dimly illuminated by white fluorescent lamps. The subject's eyes were shielded from room illumination by an eyepiece.

PROCEDURE

The symbols were shown one at a time to one subject at a time. Different sequences were used to prevent the subject's anticipating the symbols.

The subject was required to name one and only one of the 36 alphanumerics every time a symbol was exposed. The symbol shown and the symbol called were both recorded. After the subject had seen 45 symbols, he took a rest of one or two minutes, followed by the second set of 45 symbols. A rest followed each fourth of the total of 180 symbols shown in each session; the sessions lasted approximately 20 minutes. Only one font was used in a session; one session was given in the morning, and another in the afternoon.

The same three well-practiced subjects participated in all three experiments, and the fonts being studied were given in a sequence to balance the effects of practice. The subject was given a photographic print of the font to be shown during a session, and he could refer to the print at any time to refresh his memory or to check on a symbol's appearance before responding. The subjects were instructed not to hurry and, when in doubt, to consider their response before giving it.

RESULTS AND CONCLUSIONS

Although six sessions were given each subject with both the Idealized Hazeltine (Figure 3) and Leroy (Figure 5), difficulties with the apparatus permitted the symbol brightness to vary too much during three of the sessions with each font. The errors for each subject with each font are shown in Table I, for the other three useful sessions with each font. It appears that the two fonts were not different in the total errors made.

The distribution of the errors for Leroy are shown in the confusion matrix of Table II. Each row of the matrix represents the symbol shown to the subject, and a column entry indicates the number of times that the column symbol was called out in error when the row symbol was actually shown. The symbol with the most error was C (see in right margin of

Table I

Errors Made With Each Font in Experiment 1

Subject	Leroy		Idealized Hazeltine	
1	29 41 49	119	35 33 33	101
2	28 20 30	78	27 22 27	76
3	21 18 26	65	47 28 16	91
SUMS		262		268
Average per session		29		29

Table 1), and 8, 0, B, D, 5, Q, and S followed in that order, these eight symbols yielding 52 percent of the total error. The C-G (this means C-called-G and G-called-C) and the B-8 confusions were the most outstanding.

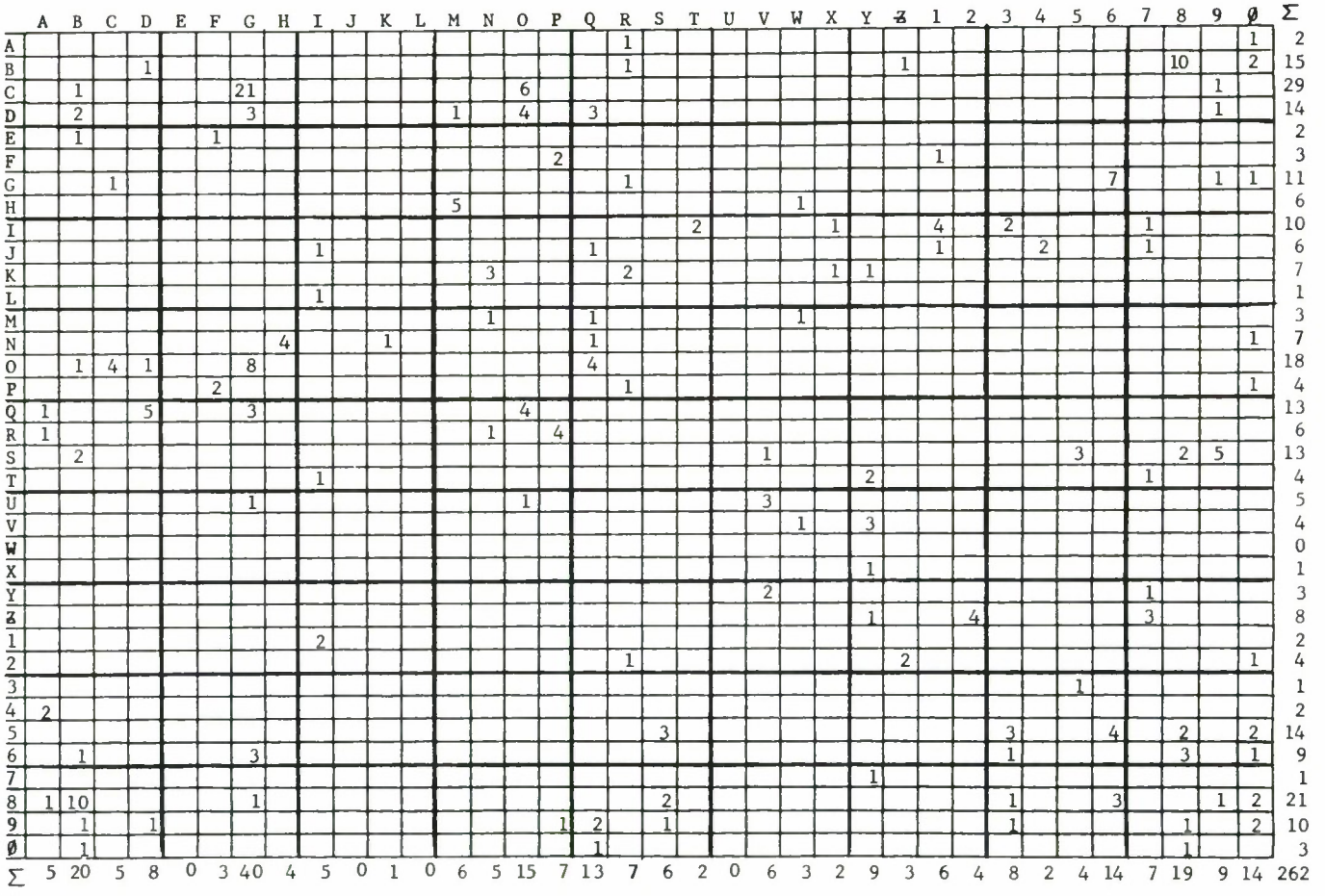
The confusion error matrix for Idealized Hazeltine is in Table III. The symbol with the most error was D, and Q, S, O, C, M and N followed in that order, these seven symbols yielding 52 percent of the total error. The S-5, M-N, D-called-B, D-0, I-1, and C-called-G confusions were the most outstanding, and several others occurred with slightly lower frequencies.

Table II

Confusion Matrix for Leroy in Experiment 1

Character Called

Character Shown



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																		1																			1	2
B				1														1								1									10		2	15
C		1					21								6																				1		29
D		2					3						1		4		3																		1		14
E		1				1																															2
F																2											1										3
G			1															1														7			1	1	11
H													5										1														6
I									1											2				1			4		2				1				10
J										1							1										1			2			1				6
K														3				2						1	1												7
L									1																												1
M														1			1						1														3
N								4			1						1																			1	7
O		1	4	1			8										4																				18
P						2												1																		1	4
Q	1			5			3								4																						13
R	1													1		4																						6
S		2																				1									3			2	5		13
T									1																2								1				4
U							1								1							3																5
V																							1		3													4
W																																					0
X																									1													1
Y																						2											1					3
Z																									1			4					3					8
1									2																													2
2																		1									2									1		4
3																															1							1
4	2																																					2
5																			3										3			4		2		2	14
6		1					3																						1					3		1	9
7																									1													1
8	1	10					1												2										1			3			1	2	21
9		1		1												1	2		1										1					1		2	10
Ø		1															1																	1			3
Σ	5	20	5	8	0	3	40	4	5	0	1	0	6	5	15	7	13	7	6	2	0	6	3	2	9	3	6	4	8	2	4	14	7	19	9	14	262

Table III

Confusion Matrix for Idealized Hazeltine in Experiment 1

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A		1						1										7																1			10
B																1		2																3		4	10
C		1					11																									6				1	19
D		12													8		2																	4		1	27
E						2	2					1																			2						7
F																1																					1
G																																3					3
H	1												2										7														10
I																				1				1			8										10
J																																					0
K																																					0
L																											1										1
M	1							6						6																								13
N	1							3					7										1															12
O		2		4			1										3																	4		6	20
P	1																																				1
Q		2		1			2								4						3													5		10	27
R		1														9																					10
S																															20	2					22
T									1																												1
U								1																													1
V																							3														3
W								1						2																								3
X											1																										1
Y																																					0
Z		2																1	1										2					3			9
1		1							4																												5
2																											6		1								7
3		1																													1						2
4																																					0
5		1																	3										1								5
6																															1					1	2
7																																					0
8		4					2												1													1				1	9
9							1										1	1	1															1		1	6
Ø		2					1								1																	1		6			11
Σ	4	30	0	5	0	2	20	12	5	0	1	1	9	8	13	11	6	11	6	1	3	0	11	1	0	6	9	0	4	0	24	13	0	27	0	25	268

In summary, the results indicate no difference in the total errors made for the two fonts, by which one may conclude that the fonts are equally legible. The errors with Idealized Hazeltine were distributed widely among the symbols most frequently confused, indicating that several symbols will need to be changed in order to reduce the errors and make the symbol set more legible.

The question arises as to whether the results for the Idealized Hazeltine will be the same when the symbols are printed on a cathode ray tube. A partial answer to this question is the purpose of the next experiment.

SECTION III

EXPERIMENT 2

APPARATUS AND PROCEDURE

The apparatus and procedure were the same as in the first experiment except that the two fonts were Idealized Hazeltine (Figure 3) and Simulated Hazeltine (Figure 4) and only two sessions were given to each subject for each font.

RESULTS AND CONCLUSIONS

The errors for each subject in each session for each font are in Table IV. The average error per session for Idealized Hazeltine was nearly the same as in Experiment 1, but the error for Simulated Hazeltine was much greater.

The distribution of errors for Idealized Hazeltine is in Table V. The symbols with the most error, in rank order, were D, Q, O, 8, S, B, R, 5 and ∅, the errors for those 9 symbols comprising 54 percent of the total error. The D, O, Q, S, 5 and 8 were among those symbols whose errors comprise half of the total in both the first and second experiments. The errors attributable to specific intersymbol confusions were more widely distributed than was the case in the first experiment, and the three symbols called most in error were ∅, Q and R.

The error matrix for Simulated Hazeltine is in Table VI. The rank order of symbols with the most error was C, 8, O, S, B, D, P, 6, ∅, G and 5, their errors being 50 percent of the total. The rank order correlation

coefficient between the Idealized and Simulated Hazeltine, when the symbols were ranked from most to least errors, was 0.69, which is statistically significant beyond the 1 percent level. *

It is concluded that the two fonts are alike in the distribution of errors among the symbols but unlike in the total errors made, the Simulated font being the less legible.

Table IV

Errors Made With Each Font in Experiment 2

Subject	Idealized		Simulated	
1	42		66	
	31	73	65	131
2	24		43	
	19	43	34	77
3	19		58	
	33	52	55	113
Sums		168		321
Average per session		28		54

In order to reduce the errors of identification of symbols in the Hazeltine font, the results of the first two experiments indicate that the C, D, O, S, 5, 8 and ∅ should be modified. In addition, the second experiment revealed a confusion between F and P, and between I and 1 (see Table VI). Some evidence

* See page 149 in Reference 15.

Table V

Confusion Matrix for Idealized Hazeltine in Experiment 2

Character Called

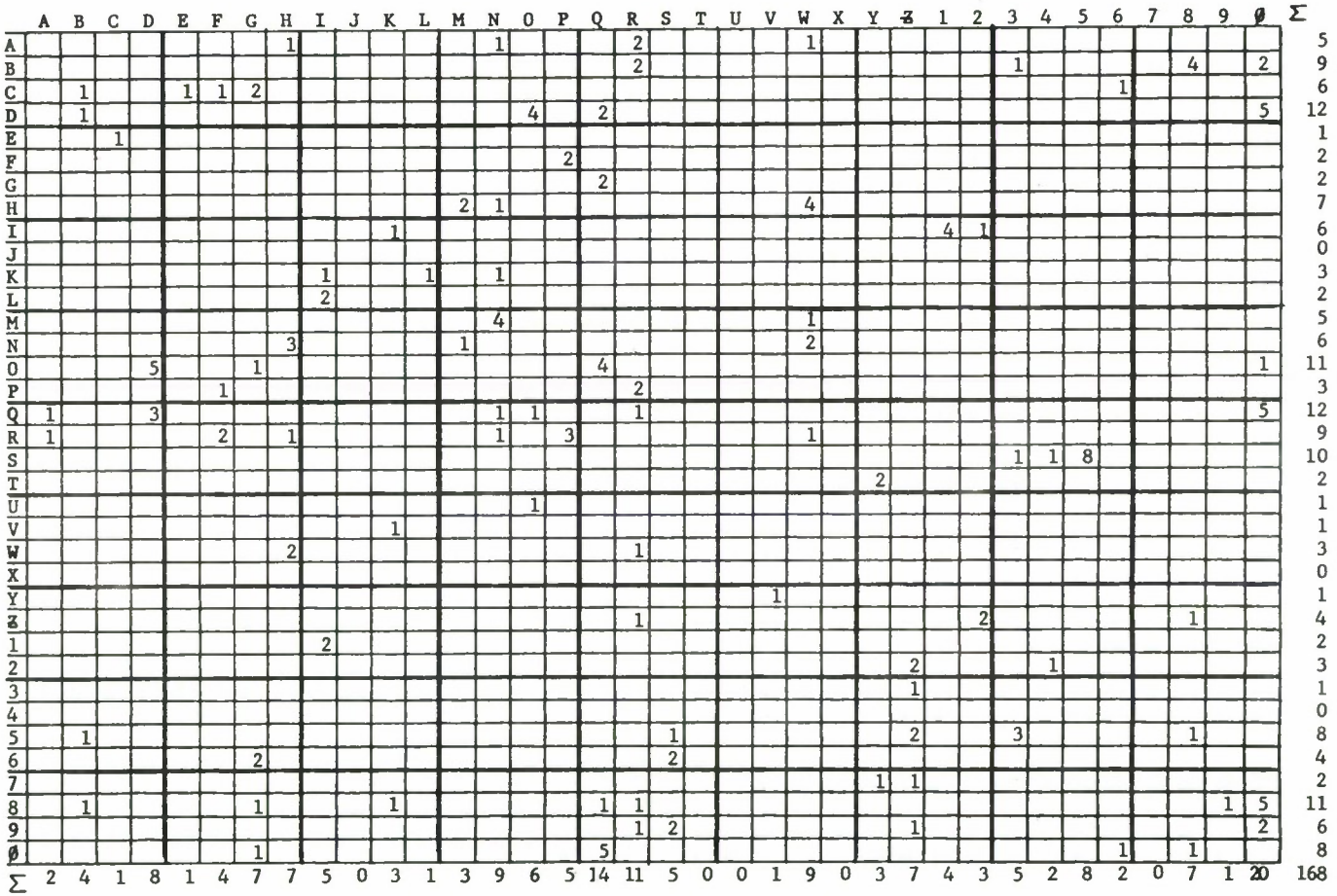


Table VI

Confusion Matrix for Simulated Hazeltine in Experiment 2

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A								4					2	1			1	1						1													10
B	1				2	1	1									1		6								1								2			15
C					1	4	3	1			2	4			1	1	1																				18
D		4													7		1																		1	1	14
E			1			3						1																								1	6
F									1									1																			2
G	1					1					1			1			4	3																		1	12
H												1		1										5													7
I																				4					1		5										10
J																											1		1	1							3
K						2								1				1								1											5
L			1		1						1			1																							4
M														7										1													8
N								3					6										1														10
O							1	1									10	1			3																16
P						13																											1				14
Q	3						2								3			1					1											1			11
R						2					1					3																						6
S							1																	1		3		1	1		7	1				1	16
T									3																		4						2				9
U				1				1						2									3												1		8
V																								3	3			1							1	1	9
W								1			2													1														4
X																		1				1			1												3
Y																																					0
Z					4	1												3										1								2	11
1									6	1										1					1												9
2						1												1						1		8											11
3	1								1	1																	1										4
4																																					0
5	1																		5										3						2	1	12
6					2		5				1	1			1							1												1		1	13
7																				1								1									2
8	1			1								1			1	1	5	3								1										4	18
9	1														1		1	2	1																	2	8
Ø	2		1		1		2								1		2	2														1			1		13
Σ	11	4	3	2	11	28	15	11	11	2	8	8	8	14	15	6	25	26	6	6	3	2	10	8	6	14	11	4	5	1	7	2	3	4	6	15	321

of P-F and I-1 confusions is seen in Tables V and III. Therefore, the C, D, O, P, S, 1, 5, 8 and Ø were modified as shown in Figure 6.

The high correlation between the Idealized and Simulated fonts in this second experiment indicated that the specific confusions among the symbols could be studied with the idealized symbols. The idealized symbols are much easier to produce because they involve only art work and do not require photographing the scope. Since the total error may change with practice, the Leroy and Idealized Hazeltine fonts should be tried along with the Modified Idealized Hazeltine to provide a better baseline for comparisons of the fonts. Therefore, it was concluded that the three fonts should be compared in a third experiment.

SECTION IV

EXPERIMENT 3

APPARATUS AND PROCEDURE

The three subjects, the apparatus, and the procedure were the same as in the first two experiments. Each subject was given two sessions with each of the three fonts.

RESULTS AND CONCLUSIONS

The errors made by each subject in each session for each font are shown in Table VII. The total errors for Leroy and Idealized Hazeltine were again comparable, and the total error for Modified Idealized Hazeltine

Table VII

Errors Made for Each Font in Experiment 3

Subject	Leroy	Idealized Hazeltine	Modified Idealized Hazeltine
1	19, 8 → 27	19, 12 → 31	13, 5 → 18
2	16, 10 → 26	8, 11 → 19	3, 6 → 9
3	8, 10 → 18	17, 17 → 34	2, 4 → 6
Sums	71	84	33
Average per Session	12	16	6

was much smaller, being 46 percent of the total for Leroy and 39 percent of the total for Idealized Hazeltine. The total errors for Leroy and Idealized Hazeltine in this experiment were less than was found in the first experiment (see Table I); the average error per session decreased from 29 to 12 for Leroy, and from 29 to 16 for Idealized Hazeltine. Since the three fonts were given in a scrambled order in this experiment, the effects of practice cannot account for the relatively lower error found for the Modified Idealized Hazeltine font.

It is concluded that the Modified Idealized Hazeltine font is more legible than the original Idealized Hazeltine.

The distribution of errors for Leroy is shown in Table VIII. The rank order of symbols from greatest to least error was C, O, and Q, these three yielding 50 percent of the total error, with 5, 8 and B contributing an additional 28 percent. The C-G, B-8, O-Q and O-called-C were the most outstanding confusions. The high frequency of error for the symbols B, C, O, Q, 5 and 8 appears to have remained after practice had reduced the total error made with Leroy.

For Idealized Hazeltine, the confusion matrix is in Table IX. The O, M, 8, S, 1 and Ø contributed 50 percent of the total error. The most frequent confusions were O-Q, I-1, S-5, M-N, and B-8. It appears that the same symbols contributed most of the errors made for Idealized Hazeltine and Leroy in all three of the experiments.

The confusions for Modified Idealized Hazeltine are shown in Table X. The errors were distributed more evenly over the matrix than was the case for the other two fonts. While the M-N and O-Q confusions also occurred with this font, they were much less frequent and less marked among all of the errors made.

Table VIII

Confusion Matrix for Leroy in Experiment 3

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A									1																					1				5			1
B							14								4																						5
C			1																																		0
D																																					0
E			1															1									1										1
F																																					1
G																																					0
H																																					0
I																																					0
J																																					0
K																																					0
L																																					0
M			6														2																				8
N																		1																			1
O			2				2								4																						8
P																																			1		0
Q																																	1				1
R																																1					1
S																																					0
T																																					0
U																																					0
V																																					0
W																																					0
X																																					0
Y																						2															2
Z																																					0
1									2			1																									3
2																																					0
3																														1							1
4																																					0
5																			3												4						7
6							2																														2
7																																					0
8		6																																	1		7
9																																			1		1
Ø																																					0
Σ	0	6	10	0	0	0	18	0	3	0	0	1	0	0	8	0	2	2	3	0	0	2	0	0	0	0	1	0	0	1	1	4	1	5	1	2	71

Table IX

Confusion Matrix for Idealized Hazeltine in Experiment 3

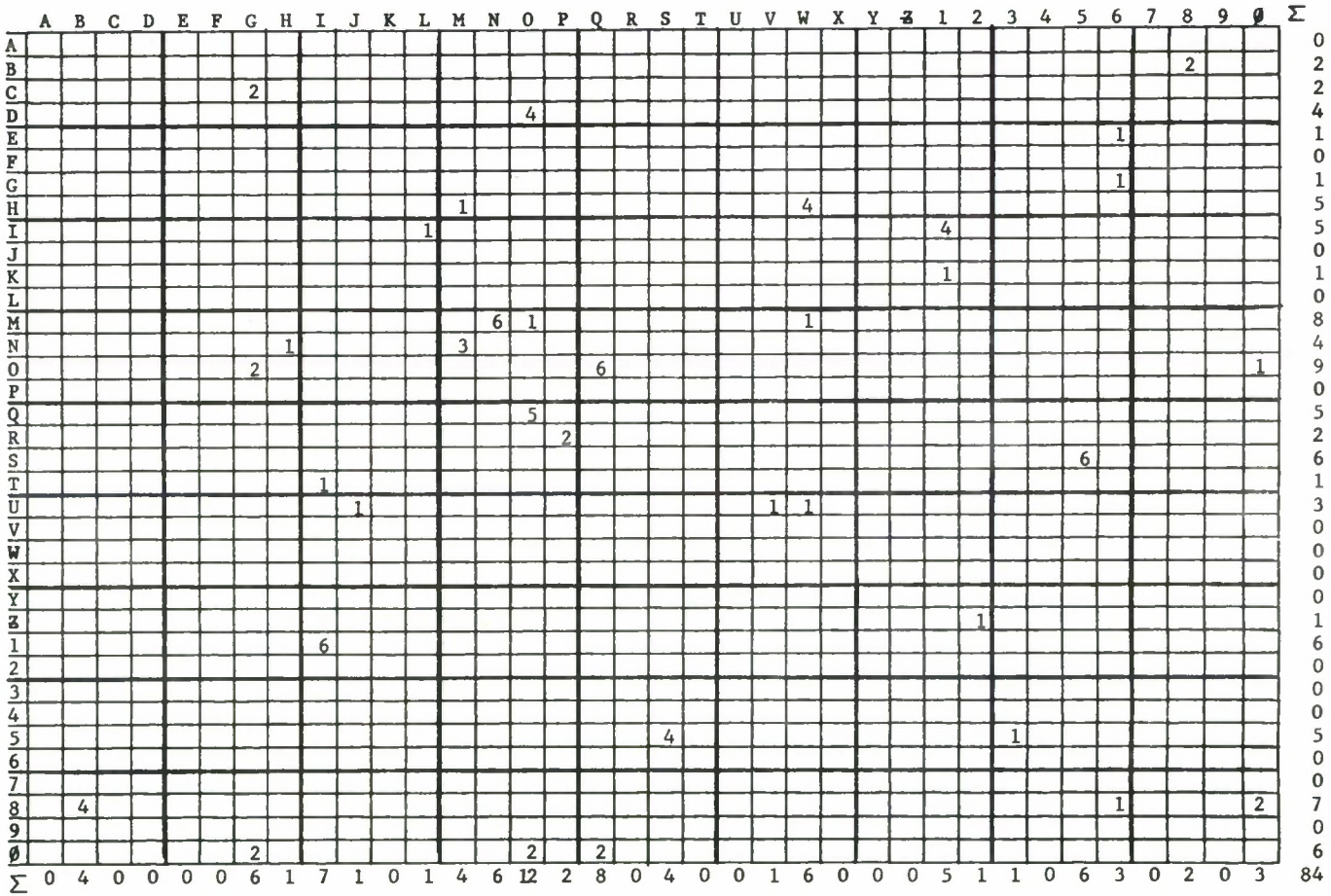
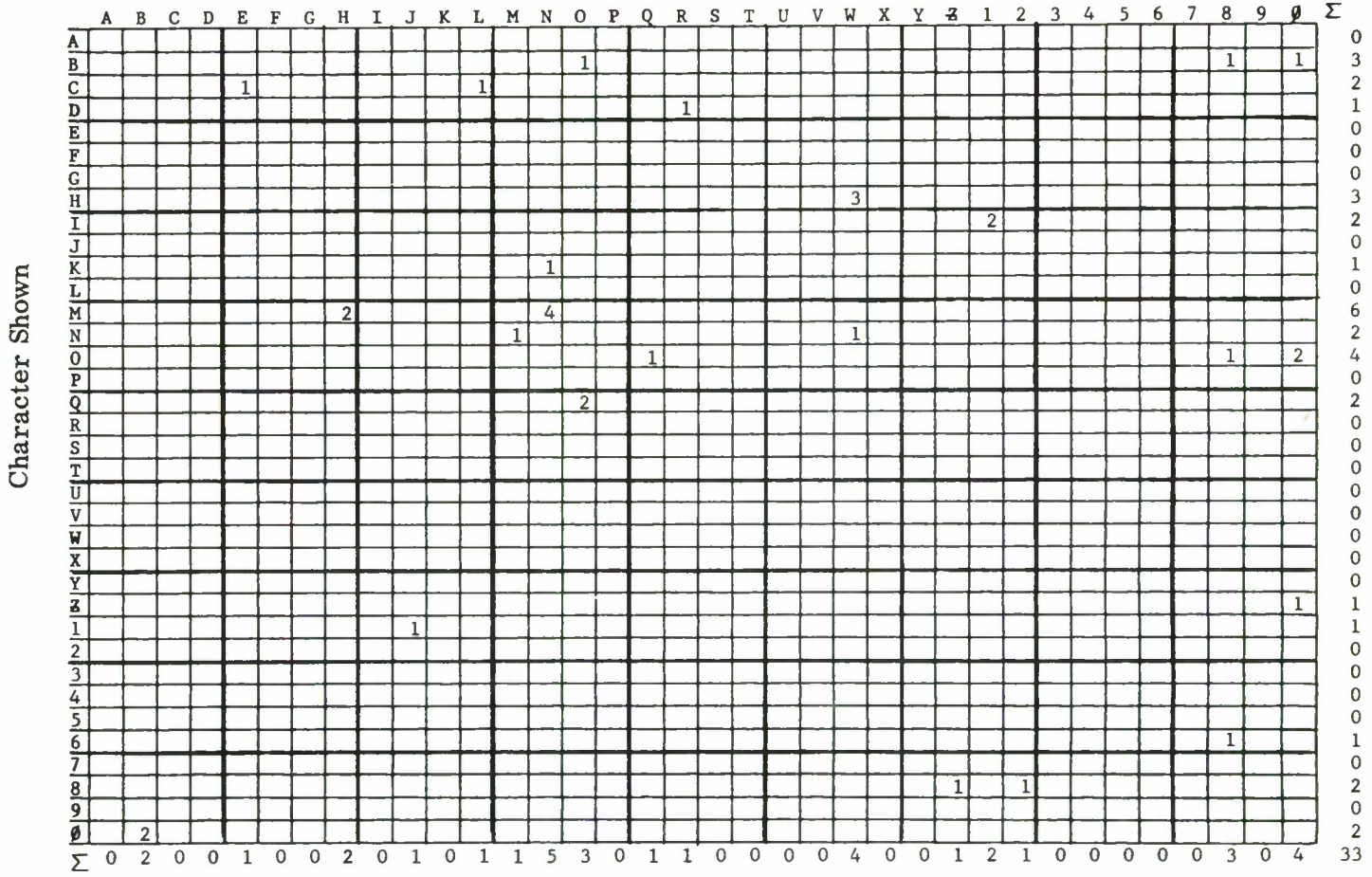


Table X

Confusion Matrix for Modified Idealized Hazeltine in Experiment 3



It is concluded that the error reduction found for Modified Idealized Hazeltine is related directly to the symbol modifications shown in Figure 6.

SECTION V

SUMMARY DISCUSSION AND RECOMMENDATIONS

The similarity of error for Leroy and Idealized Hazeltine is not difficult to appreciate when it is remembered that the font for digitalized TV was intentionally made to look much like a standard font, such as the Leroy. Indeed, the similarity of errors indicates the degree of success. The standard shapes of letters and numerals in a typical alphanumeric font seem to cause errors of confusion among certain of the symbols.[5, 6] If such errors of confusion are to be reduced, it follows that the font must contain symbols of unconventional appearance. The D, S, and 8 in Figure 6 are typical of the most radical departures from conventional shape in the set, but it is clear that they and the others are recognized with small error and little practice. Perhaps an esthetically unpleasing appearance is the price to be paid for better legibility.

The superior performance of the subjects with the Modified Idealized Hazeltine raises two questions of general interest. The first question is whether these symbols will be associated with better performance in other kinds of reading tasks, such as word recognition. The second question is whether the better results will be obtained when the symbols are actually printed on a cathode ray tube. Both questions will be answered only by actual trial, but the results of the second and third experiments suggest that the Modified Hazeltine symbols are more suitable than their earlier counterparts for use on displays.

It is recommended that further studies be performed to determine the most legible font for a CRT, and that these experiments include reading tasks

in addition to the controlled-exposure time, single-symbol, recognition tests reported in this paper.

It is also recommended that the Modified font be used on displays in order to make them more legible.

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13. ABSTRACT

The relative legibility of numerals and capital letters in four fonts, standard Leroy, an Idealized Hazeltine, a Simulated Hazeltine and a Modified Idealized Hazeltine, was studied in three experiments using a controlled exposure-time, single-symbol, recognition test. The Hazeltine fonts were constructed of TV lines digitally controlled to generate symbols of elements in a five-column by seven-row rectangular matrix. The Hazeltine font was found to be as legible as the Leroy, but losses in legibility were found for photographic simulations of the symbols as they appear on a TV tube. The modified font was found to be superior in legibility, and is recommended for display use. Further study should be done on a TV tube and would best employ other kinds of legibility tests.

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